ASSESSING ROLLER BEARING FAILURE: IMPACT OF LOAD, VIBRATION, AND TEMPERATURE ON TWO MATERIALS – A REVIEW

[1]Devendra Kumar, [2]Prof. Abhilesh Dubey, [3]Prof. Girish Khare

[1]Department of Mechanical Engineering, Oriental Institute of Science and Technology - [OIST], Bhopal, India

[2]Department of Mechanical Engineering, Oriental Institute of Science and Technology - [OIST], Bhopal, India

[3]Department of Mechanical Engineering, Oriental Institute of Science and Technology - [OIST], Bhopal, India

Email [1]dgrahi28@gmail.com, [2]abhileshdubey@oriental.ac.in

* Corresponding Author: Devendra Kumar

Abstract: *Health Condition Monitoring (HCM) of rotating machinery is critical for ensuring industrial process reliability. This review paper explores fault detection methods, including identification of healthy and faulty states, and diagnosis of fault types, utilizing models and signals such as vibration and acoustic emissions. Bearings, integral to most rotating devices, are prone to faults, accounting for a significant portion of equipment failures. The paper discusses the importance of reliability in industrial equipment, emphasizing the role of maintenance in achieving long-term asset life. Structural damage identification and vibration-based health monitoring techniques are also explored. Additionally, the review provides an overview of various types of roller bearings, their construction, advantages, and common applications.*

Keywords: *Health Condition Monitoring, Fault Detection, Bearings, Reliability, Maintenance, Structural Damage Identification, Vibration-Based Health Monitoring, Roller Bearings.*

I. INTRODUCTION

Monitoring the health of rotating equipment is vital for ensuring the dependability of industrial operations. This process involves the early detection of any malfunctions by differentiating between normal and abnormal conditions and pinpointing the specific issues present. Techniques like analyzing vibration and sound patterns are commonly used for this purpose. Bearings play a critical role in the function of rotating machines and often account for a significant proportion of the malfunctions encountered, with studies indicating they can be responsible for nearly half of all faults in certain machines [1]. Reliability is an important term, which is associated with the assessment of the life of different industrial equipment's and products. Product with high reliability is greatly dependent upon better product design. However, although the product is having superior design, it deteriorates over time, because in the real environment or operating conditions, they are operated under high stress or load. Thus, to achieve a satisfactory level of reliability for the life of an asset, maintenance is the only key. In the earlier days, maintenance is only referred as breakdown maintenance (or run to failure maintenance), which takes place only after the break down of the machine or the component. No planning is done for this type of maintenance [2].

Rolling element bearings are essential components that significantly impact the operational efficiency of both domestic and industrial machinery. The seamless performance of these machines is largely contingent on the health of the bearings, which when compromised, can lead to machinery malfunctions or catastrophic failures. This susceptibility to defects necessitates vigilant monitoring for potential issues, which can originate during production or use. Timely detection of such defects is critical for maintaining machine health and ensuring the quality of the bearings [3]. In the realm of machinery maintenance, the significance of rolling element bearings cannot be overstated. They are ubiquitous in mechanical systems due to their affordability and operational simplicity. Indeed, the smooth running of rotating machinery hinges on the condition of these bearings, which are implicated in a majority of machine failures—estimated to cause between 45% and 55% of breakdowns [4]. Bearings are commonplace in rotary machinery systems and are subject to a variety of stressors that can induce rolling contact fatigue, one of the primary modes of bearing failure. The structural integrity of these bearings during service is crucial, as fatigue can lead to serious structural failures with considerable safety risks. Furthermore, the detection of structural damage within the broader field of civil engineering is of paramount importance due to the safety implications involved. Structural damage is technically characterized by reductions in defining parameters of a structure, such as stiffness and mass, and can often be quantified by observing changes in modal characteristics, providing a method for assessment and prevention of failure [5].

Vibration-based health monitoring of structures has been a good tool for evaluating structural conditions and detecting possible damages in early stages. Continuous ambient vibration monitoring for identifying modal parameters is one of the common strategies for structural health monitoring. Changes in measured dynamic modal parameters are usually used as damage-sensitive features since they are well correlated to physical properties of a structure [6]. All industries are becoming smarter as part of the fourth industrial revolution. Smart industries increasingly rely on Prognostics and Health Management

(PHM) systems to ensure the reliability and efficiency of their operations. PHM approaches are designed to systematically monitor and manage the health of systems, providing solutions that are both comprehensive and customizable. The methodology of PHM can be broken down into three key stages, starting with the detection of faults within the system [7]. Rolling bearings play a critical role as primary transmission elements in many types of rotating machinery. The uninterrupted operation of these bearings is crucial to the overall functioning of the mechanical systems they are part of. However, bearings are vulnerable to skidding under conditions of variable speeds or loads, which can markedly degrade their performance. Moreover, any defect on the bearing's raceway surface can introduce repetitive shocks as the rolling elements encounter the defect during operation [8].

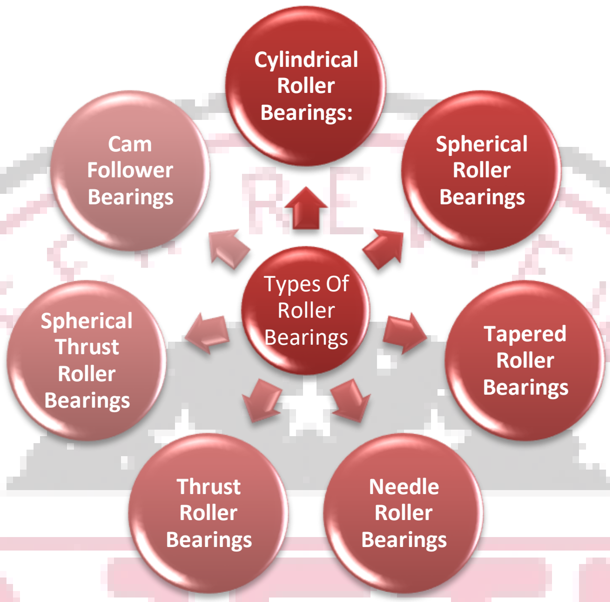

Figure 1 Types of Roller Bearings

Fig. 1 demonstrates the Types of Roller Bearings Roller bearings are mechanical components designed to facilitate rotational or linear motion while minimizing friction between moving parts. There are several types of roller bearings, each with specific designs tailored to different applications. Here are the common types of roller bearings.

II. MATERIALS OF BEARING

Bearings are crucial mechanical components that facilitate smooth motion by reducing friction between moving parts. The choice of material for bearings is fundamental to their performance, longevity, and reliability in diverse applications. Various materials are employed in bearing manufacturing, each selected based on specific requirements such as load capacity, speed, temperature, and environmental conditions. Here's a comprehensive overview of the materials commonly used in bearings. Journal Bearing is a machine element that supports, and radially position a rotating shaft. Bearing's performance and efficiency affect the successful operation of the systems/mechanisms. So, bearing materials must be carefully chosen, to make these systems run successfully and meet the performance expectations. Rolling contact bearings offer lower friction than sliding contact bearings.

The bearing material should have following characteristics from the service point of view.

- High strength to sustain bearing load, high compressive and fatigue strength.
- High thermal conductivity to dissipate the heat quickly.
- Low coefficient of friction.
- Less wear and tear.
- Low cost.
- Bearing materials should not readily weld itself to the shaft material.
- Good corrosion resistance in case the lubricant has the tendency to oxidize the bearing.
- Good conformability. The bearing should adjust to misalignment or geometric errors. Materials with low modulus of elasticity usually have good conformability.

Cast iron, brass and alloy materials viz., bronzes (copper-tin), Babbitt (alloys of tin-copper-lead-antimony), copper-lead alloys and aluminum-tin alloys are used for making sliding contact bearings. Rubber and synthetic composite materials are also used for certain applications (synthetic bearings).

The materials for rolling contact bearings should have the capability of being hardened to required level. They require high resistance against wear and fatigue and stability up to 125°C. The inner and outer rings and rolling elements are made from alloy steel based on Cr-Ni, Mn-Cr, and Cr-Mo.

III. LITERATURE REVIEW

Wei et al. (2016) conducted finite element (FE) simulations to compare a newly designed deep end-cavity roller with a traditional straight-profile roller bearing. Their findings suggested that the new roller design could achieve performance on par with logarithmic profile roller bearings by reducing the intense stress concentrations at the roller apexes.

Demirhan and Kanber (2008) utilized the ANSYS software for a detailed examination of how stress and displacement are distributed in cylindrical roller bearing rings. They discovered that these distributions vary between the inner and outer ring surfaces and are not uniform throughout the ring's height, primarily due to the high stress concentrations at the contact points.

Vernersson (2007) developed an FE model to map out the process of heat transition from the rolling wheels into the rails, considering a thin film with thermal contact resistance at the wheel-rail interface. This model, which aligns with empirical data, provides a useful tool for designing efficient tread braking systems suitable for various rail vehicles, including freight and passenger trains.

Kushwaha et al. (2020) conducted a detailed study of heat transfer within a bearing system, employing the finite element method to model and analyze a standard ball bearing and its surrounding environment. By simulating the temperature dynamics over time, with the variable of rotational speed, they aimed to determine the rate at which temperature changes within the system and whether the bearing would hit a critical temperature threshold — such as the maximum temperature endurance of the lubricant or the bearing metal. Their findings revealed that an increase in rotational speed leads to a quicker attainment of thermal equilibrium within the system. However, at none of the rotational speeds tested did the bearing approach a critical temperature limit. Additionally, they explored the occurrence of scuffing, a type of failure linked to thermal conditions within the bearing.

Wu& Tan (2018) analyzed a thermo-mechanical coupling analysis model of the spindle-bearing systembased on Hertz's contact theory and a point contact non-Newtonian thermal elasto-hydrodynamiclubrication (EHL) theory are developed. Within the comprehensive model under discussion, a host of factors are meticulously integrated to simulate the operational dynamics of the spindle-bearing system accurately. These factors include the preload on the bearings, the influence of centrifugal forces, the gyroscopic moments, and the state of lubrication, all of which are critical to the performance and longevity of the system. Drawing from the principles of heat transfer theory, the model constructs a detailed mathematical representation of the temperature field within the spindle system, allowing for a nuanced analysis of how the spindle's cooling mechanisms affect its temperature distribution. The simulations, when corroborated with real-world data, indicate a direct and significant relationship between the preload exerted on the bearings and the amount of frictional heat generated—friction being a fundamental source of heat within such systems. The role of the cooling fluid emerges as equally pivotal; it is instrumental in maintaining the heat balance by mitigating the heat accumulation. An imbalance caused by inadequate cooling can result in an increase in thermally-induced preload, which in turn can increase friction and heat—creating a vicious cycle. This can escalate to a point where the spindle system experiences thermal overload, leading to potential system failure. Thus, the model underscores the delicate interplay between mechanical preloading, heat generation, and the criticality of effective cooling in preserving the functional integrity of spindle systems.

Subramaniam et al. (2016) conducted a study to examine the heat transfer characteristics of a conventional ceramic ball bearing, focusing on how heat dissipation, temperature profiles, deformations, and thermal stresses vary with changes in rotational speed. Their findings indicated a direct correlation between heat generation and temperature rise within the bearing. Analysis of different operational speeds revealed that rotational velocity is a critical factor affecting bearing temperature, with higher speeds leading to higher temperatures. The relationship between the temperature and the rotational speed was such that the peak temperature experienced by the bearing was determined by the amount of heat generated. Additionally, as rotational speed increased, there was a corresponding increase in displacement, which in turn caused deformation and induced thermal stresses within the bearing. The investigation also noted that rotational speed exerted a significant impact on the bearing's stiffness.

IV. CYLINDRICAL ROLLER BEARING

Cylindrical roller bearings come in an extensive assortment of styles, series, variations, and sizes. Cylindrical roller bearings are differentiated by several design features that cater to specific application needs. These features include variations in the number of roller rows and the presence or arrangement of flanges on the inner and outer rings, which contribute to the bearing's load-handling capabilities and suitability for high-speed operations. Additionally, the design incorporates different cage constructions and materials, enhancing the bearing's durability and reducing friction. These bearings excel in environments where substantial radial loads are present and are engineered to manage axial displacement—although this does not apply to versions with flanges on both rings, which restrict axial movement. Their design is inherently stiff, offering minimal friction resistance and promising longevity under demanding conditions. Moreover, the availability of cylindrical roller bearings in both sealed and split designs allows for greater versatility in usage, addressing a broad spectrum of industrial requirements while ensuring maintenance. The sealed variants offer protection for the rollers from external contaminants, water, and dust, while also retaining lubricant and preventing contamination entry, all of which contribute to reduced friction and increased durability.

Figure 2 Cylindrical rolling bearing

Cylindrical roller bearings are pivotal in the industrial realm, facilitating the smooth functioning of machinery by managing heavy radial loads during high-speed rotations. These bearings are distinct for their cylindrical rollers that lay parallel, offering uniform load distribution over the full length of the roller for optimal load-bearing efficiency. The uniformity in load distribution is a key advantage, as it allows these bearings to handle intense radial stresses without compromising on performance. Their design minimizes friction, which is essential in applications where the efficiency and reliability of machinery are critical. This low friction is not only beneficial for energy conservation but also prolongs the operational life of the bearings and the machinery they support. As a result, cylindrical roller bearings are considered an integral component in sectors that predominantly deal with radial forces and where the durability and dependability of mechanical components are of utmost importance. Their use ranges from heavy machinery to precision instruments, underscoring their versatility and essential role in a wide array of industrial applications. Here's a detailed exploration of cylindrical roller bearings, their construction, advantages, and common applications:

A. Construction and Design

Cylindrical roller bearings, fundamental to the mechanics of various industrial machinery, feature an array of cylindrical rollers positioned and held in place between two races; these races usually manifest as an inner ring and an outer ring. The configuration is such that the rollers are meticulously guided by ribs that can be located on either the inner or the outer ring, a design that guarantees their precise alignment during the dynamic stresses of operation. Integral to this system is the cage, typically constructed from robust materials like steel, which plays a crucial role in maintaining the rollers at consistent intervals. This cage acts as a spacing device, ensuring that the rollers are evenly distributed and preventing direct contact between them, thereby reducing friction and the subsequent wear that could otherwise compromise the bearing's efficiency and longevity. The strategic assembly of these components within the cylindrical roller bearing not only enhances performance under radial load conditions but also contributes to the overall reduction of maintenance frequency and extends the service life of the equipment they are a part of.

B. Types of Cylindrical Roller Bearings

Single Row Cylindrical Roller Bearings are designed with a singular row of cylindrical rollers, making them well-suited for withstanding substantial radial loads, which is why they are frequently chosen for use in a variety of machinery including electric motors, pumps, and compressors. Their structural simplicity allows for ease in installation and maintenance, catering to a broad range of industrial needs. On the other hand, Double Row Cylindrical Roller Bearings are characterized by their two sets of cylindrical rollers, which enable them to handle not only higher radial loads but also a significant amount of axial loads in either direction. This design feature makes them indispensable in scenarios where robust performance is demanded, such as in heavy industrial machinery and gearboxes where the operational stress is considerable. The dual-row arrangement also often means these bearings can tolerate misalignment and operate effectively in applications where the load conditions are complex and dynamic. The capacity of double-row bearings to deal with both radial and axial forces simultaneously makes them a versatile and reliable choice for a myriad of heavy-duty applications, spanning from rolling mills to large motors and wind turbines, where both the precision of operation and durability are paramount.

C. Advantages of Cylindrical Roller Bearings

High Radial Load Capacity: Cylindrical roller bearings excel at handling radial loads, making them suitable for applications with predominantly radial forces.
High-Speed Operation: Their low friction design enables efficient high-speed rotation, making them ideal for applications where speed is a critical factor.

Space Efficiency: Cylindrical roller bearings are relatively compact, making them suitable for applications with limited space.
Easy Installation and Maintenance: Their simple design and separable components simplify installation, inspection, and maintenance procedures.

D. Common Applications

Automotive Industry: Cylindrical roller bearings are used in automotive wheel hubs, transmissions, and engines, where they endure radial loads and provide reliable performance.
Industrial Machinery: These bearings are prevalent in industrial machinery such as electric motors, pumps, compressors, and conveyors, ensuring smooth operation under heavy radial loads.
Power Generation: Cylindrical roller bearings are employed in power generation equipment, including turbines and generators, where they support radial loads and contribute to the efficient functioning of the machinery.
Railway Industry: In the railway sector, cylindrical roller bearings are used in locomotives and rolling stock applications, providing reliable performance under varying operating conditions.
Hence, understanding the operating temperature and its distribution is fundamental for effective bearing condition monitoring, directly impacting the performance and longevity of equipment. Rapid increases in heat due to abnormal reasons, if not promptly addressed, can lead to continuous temperature escalation and potential overheating. It is essential to recognize that each moving part in a machine emits a distinctive vibration signal, which changes with the varying states of machine components [15]. Monitoring these signals is key, as alterations can serve as early indications of faults in their incipient stages, enabling timely detection and repairs before a major breakdown occurs. This core principle underlines the significance of condition monitoring, a systematic process of data collection and evaluation, aimed at identifying performance changes and ensuring the reliability and efficiency of machinery.

V. CONCLUSION

This comprehensive review underscores the crucial role of Health Condition Monitoring (HCM) in ensuring the reliability of rotating machinery within industrial processes. By focusing on fault detection, including identifying healthy and faulty states and diagnosing fault types, using signals like vibration and acoustic emissions, industries can proactively address potential issues. Bearings, as vital components in rotating devices, demand special attention due to their susceptibility to faults. The paper emphasizes the importance of reliability, linking it directly to effective maintenance strategies. Furthermore, the review highlights the significance of structural damage identification and vibration-based health monitoring techniques, essential tools for assessing the health of industrial systems. Additionally, a detailed exploration of various types of roller bearings provides valuable insights into their construction, advantages, and applications, contributing to a comprehensive understanding of these critical components. Overall, this review serves as a valuable resource for researchers, engineers, and practitioners involved in the field of rotating machinery and industrial equipment maintenance.

REFERENCES

[1] Cerrada, M., Sánchez, R. V., Li, C., Pacheco, F., Cabrera, D., de Oliveira, J. V., & Vásquez, R. E. (2018). A review on data-driven fault severity assessment in rolling bearings. Mechanical Systems and Signal Processing, 99, 169-196.https://doi.org/10.1016/j.ymssp.2017.06.012

[2] Malla, C., Panigrahi, I. (2019). Review of Condition Monitoring of Rolling Element Bearing Using Vibration Analysis and Other Techniques. J. Vib. Eng. Technol. 7, 407–414. https://doi.org/10.1007/s42417-019-00119-y

[3] Rai, A., & Upadhyay, S. H. (2016). A review on signal processing techniques utilized in the fault diagnosis of rolling element bearings. Tribology International, 96, 289-306.https://doi.org/10.1016/j.triboint.2015.12.037

[4] Romanowicz, P. J., & Szybiński, B. (2019). Fatigue Life Assessment of Rolling Bearings Made from AISI 52100 Bearing Steel. Materials, 12(3), 371. MDPI AG. Retrieved from http://dx.doi.org/10.3390/ma12030371

[5] Luo, J., Huang, M., & Lei, Y. (2022). Temperature Effect on Vibration Properties and Vibration-Based Damage Identification of Bridge Structures: A Literature Review. Buildings, 12(8), 1209. MDPI AG. Retrieved from http://dx.doi.org/10.3390/buildings12081209

[6] Zhong, X., Huang, Y., Bin, G., & Chen, A. (2021). Effect of the inlet oil temperature on vibration characteristics of the high-speed turbocharger rotor system. Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology, 235(10), 2086-2098.

[7] Anwarsha, A., & Narendiranath Babu, T. (2022). Recent advancements of signal processing and artificial intelligence in the fault detection of rolling element bearings: A review. Journal of Vibroengineering, 24(6), 1027-1055.

[8] Yan, C., Zhao, M., Lin, J., Liang, K., & Zhang, Z. (2020). Fault signature enhancement and skidding evaluation of rolling bearing based on estimating the phase of the impulse envelope signal. Journal of Sound and Vibration, 485, 115529. https://doi.org/10.1016/j.jsv.2020.115529

[9] Li, Y., Xu, M., Wei, Y., & Huang, W. (2016). A new rolling bearing fault diagnosis method based on multiscale permutation entropy and improved support vector machine based binary tree. Measurement, 77, 80-94.

[10] Demirhan, N., &Kanber, B. (2008). Stress and displacement distributions on cylindrical roller bearing rings using FEM. Mechanics Based Design of Structures and Machines, 36(1), 86-102.

[11] Vernersson, T. (2007). Temperatures at railway tread braking. Part 1: modelling. Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit, 221(2), 167-182.

[12] Kushwaha, N., & Patel, V. N. (2020). Modelling and analysis of a cracked rotor: a review of the literature and its implications. Archive of Applied Mechanics, 90(6), 1215-1245.

[13] Duan, Z., Wu, T., Guo, S., Shao, T., Malekian, R., & Li, Z. (2018). Development and trend of condition monitoring and fault diagnosis of multi-sensors information fusion for rolling bearings: a review. The International Journal of Advanced Manufacturing Technology, 96, 803-819.

[14] Subramaniam, S. B., Harsha, R. D., Vivek, M., & Prasad, V. D. (2016). Thermal Analysis of Ceramic Conventional Ball Bearings. Indian Journal of Science and Technology, 9, 35.

[15] Zhou, X., Zhang, H., Hao, X., Liao, X., & Han, Q. (2019). Investigation on thermal behavior and temperature distribution of bearing inner and outer rings. Tribology International, 130, 289-298. https://doi.org/10.1016/j.triboint.2018.09.031